Los Alamos
NATIONAL LABORATORY
memorandum

Los Alamos Neutron Science Center
LANSCE-1, Accelerator Physics and Engineering Group

To/MS: Distribution *wpl*
From/MS: W. P. Lysenko, LANSCE-1, H808
Phone/FAX: 7-7431/5-2904
Symbol: LANSCE-1:99-137
Date: July 14, 1999
Email: wpl@lanl.gov

MATCHING TO LINACS BY MINIMIZATION OF EMITTANCE GROWTH

Summary

I have computed an improved input beam for the SNS CCDTL by using an optimizer running the LINAC particle-tracking code. The optimizer varied the input values of α_x, β_x, α_y, and β_y and searched for the values that minimized the final transverse emittances. The resulting beam had only slightly smaller final emittances but had significantly smaller flutter, and thus a smaller maximum rms beam size, than the beam matched to the linac in the conventional manner. This result suggests that we should match by minimizing flutter. This could be done in a linear code like TRACE 3-D. Also, it appears that the optimum placement of transverse beam-size measurements in the CCDTL or in the DTL commissioning beamline (which has the same magnetic lattice) is to have the measurements one focusing period apart and continuing for several consecutive periods.

Background

Robert Garnett has studied the effects of injecting a mismatched beam into the SNS DTL[1]. Part of the purpose of his study was to determine the feasibility of measuring the level of mismatch at the DTL entrance using diagnostics placed in the CCDTL. Bob found that to detect an input beam transverse mismatch factor of 0.2 (emittance growth is seen at mismatch factors of 0.5 and above), we need to detect variations in the beam envelope size in the CCDTL of 0.1 mm. (My interest in this result arises from my work on the SNS DTL commissioning beamline, which will probably have a magnetic lattice similar to that of the CCDTL.)

Clearly, measuring the mismatch factor this way is not going to be easy. However, another fact also concerns me. If we consider the profile of the matched beam and compare it to the profile of the beam with the 0.2 mismatch, they do not appear to be very different. They both have about the same flutter. Just by looking at them, it is difficult to say which one is the matched beam and which one is the mismatched beam. (Of course, with larger mismatches, this is not the case.) Can the matched beam be improved? Then perhaps the distinction between the matched and mismatched beams would be more evident and the measurement of mismatches more believable.

Matching by Minimizing Emittance

A beam matched (to lowest order) to a periodic structure will have periodic second moments. But if the lattice parameters are not constant or slowly varying, there is no obvious way to define a

[1] R.W. Garnett, "SNS 1-Tank DTL Input Beam Mis-steering and mismatch Sensitivity Study," LANL memorandum LANSCE-1:99-053 (March 23, 1999).

matched beam. Various matching methods produce slightly different beams.

We know that mismatches, in the presence of space-charge forces, lead to emittance growth. So an natural thing to do is to determine the input beam that results in the least amount of emittance growth. We could use this as the definition of a matched beam.

To see if this makes sense, I wrote a crude optimization code that ran the LINAC simulation code. The optimizer varied the input beam Courant-Snyder parameters α_x, β_x, α_y, and β_y. It determined the values of these parameters that resulted in the smallest final transverse emittances. The actual quantity that was minimized was

$$\epsilon_x + \epsilon_y, \tag{1}$$

where ϵ_x and ϵ_y are the normalized rms emittances in the two transverse directions. The statistical error in this quantity is about 1.4% for 4,000-particle LINAC CCDTL simulations. I found that the quantity $\epsilon_x^2 + \epsilon_y^2$ had about the same statistical error[2].

I used the same random sequence in all runs of LINAC in the optimization to reduce the effects of the statistical fluctuations. The input beam in the optimization simulations was a type 5 generated distribution (uniform in 4-D) instead of the particle distributions usually used in CCDTL simulations. The optimization converged after about 1.5 days of running on a 200 MHz Pentium Pro computer. In terms of the final emittance values, the optimized input beam was not much better than the standard input beam. The table below shows the results. Note that the standard and optimized input beams have the same emittances; only the α and β values differ.

	ϵ_x	ϵ_y	$\epsilon_x + \epsilon_y$
input beam	0.0566	0.0803	0.1369
final beam (standard input beam)	0.0637	0.0658	0.1295
final beam (optimized input beam)	0.0604	0.0631	0.1235

Optimizing the input beam reduced the final value of $\epsilon_x + \epsilon_y$ by only 4.6%. However, the flutter and thus the maximum rms beam size was significantly improved for the optimized beam. Figure 1 shows the results. The upper graph shows the transverse profiles for the standard input beam. The lower graph shows the profiles for the optimized input beam. The square dots show the rms value of x at the focusing quadrupole positions and the circular dots show the rms value of x at the defocusing quadrupole positions.

[2] It would be interesting to also try the moment invariant $\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2 + \langle y^2\rangle\langle p_y^2\rangle - \langle yp_y\rangle^2 + 2\langle xy\rangle\langle p_xp_y\rangle - 2\langle xp_y\rangle\langle yp_x\rangle$ as the quantity to minimize. This would factor out the linear coupling effects and respond only to nonlinearities.

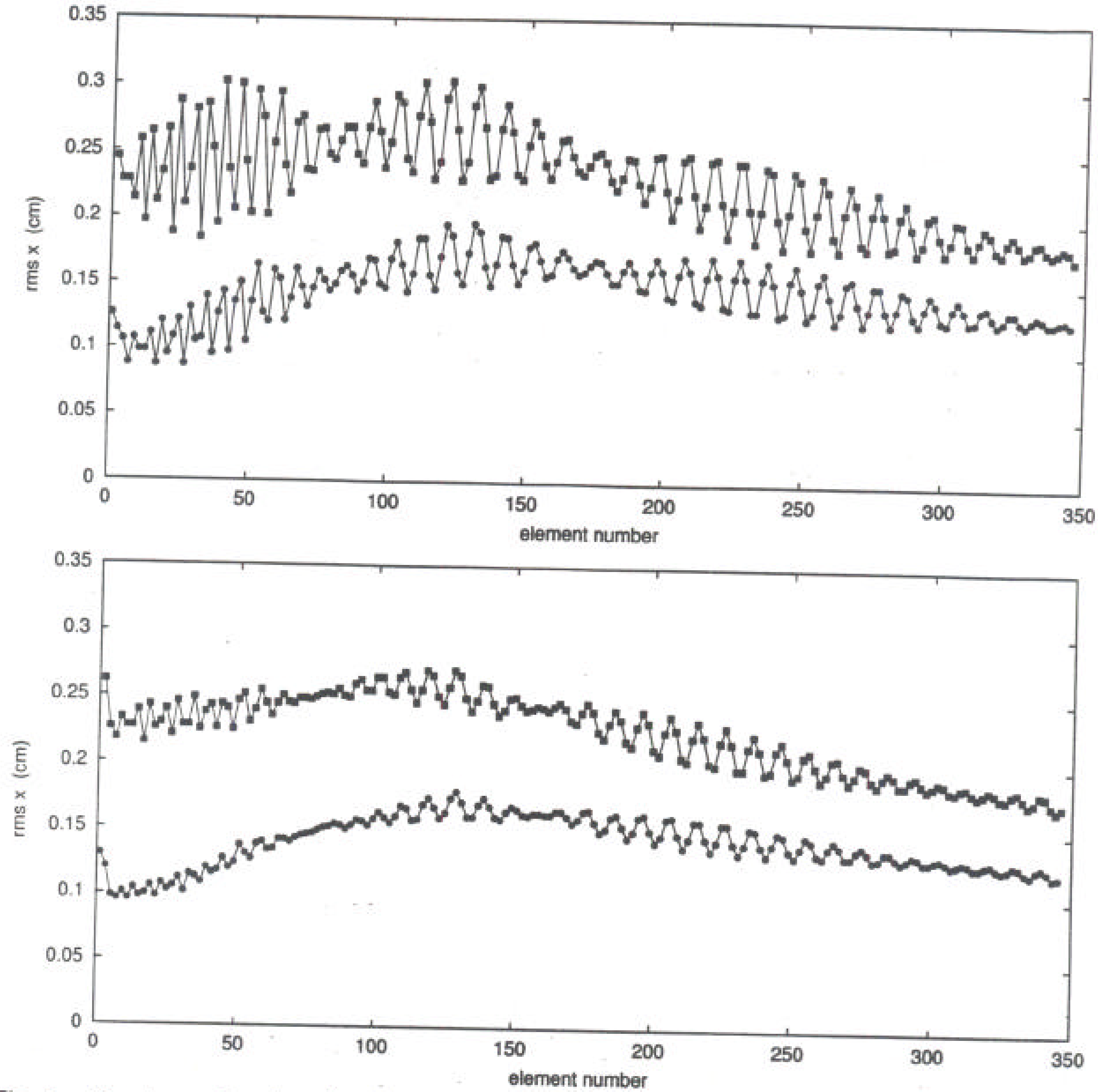

Fig. 1. Rms beam sizes in x-direction at centers of quadrupoles in the CCDTL. Beam sizes in the F quads are marked by square dots and in the D quads by circular dots. The upper graph is for the standard input beam. The lower graph uses an input beam that minimizes the final transverse emittances in the CCDTL.

Conclusion

This result suggests that there is a strong correlation between emittance growth and beam flutter, which is the variation in beam size observed at points one focusing period apart. Note that it is the local flutter that is reduced. The slow variation of the rms beam size down the machine is still there[3]. The reduced flutter was seen both at the F quadrupole and the D quadrupole positions. From what we see here, we may conclude the following:

- The best way to match (numerically and experimentally) may be by minimizing local beam flutter at some point in the machine.
- We should place beam-size measuring equipment one period apart for several consecutive focusing periods.

Because we need to look at only a few focusing periods, we can use fast linear codes like TRACE 3-D for numerical matching by minimizing the local flutter. Nonlinear space-charge effects, which lead to emittance growth only after many periods do not have to be considered. Alternatively, we could use a particle-tracking code like LINAC but tracking the beam for only a few periods and looking at the local flutter instead of the emittances at the end of the long machine.

Acknowledgments

I thank Barbara Blind and Doug Gilpatrick useful discussions and Barbara for providing the data files and codes used in this work.

Appendix

The emittance-optimization computation was done on the `pc-lysenko.atdiv.lanl.gov` computer running MS Windows NT. The files associated with this work are in the `C:\wpl\sns\optim` directory.

Files in `C:\wpl\sns\optim` directory	
`o1.for`	Optimizer code that runs the LINAC code.
`linac_bb.dat`	`linac.dat` file (from B. Blind).
`opt1.inp`	Standard `linac.inp` file (like file from B. Blind but changed distribution from particles to type 5 (4-D uniform)).
`opt2.inp`	Final (optimized) `linac.inp` file. This is the output of the optimization run.
`beamsz_start`, `beamsz_final`	`beamsz` files for standard and optimized runs.
`linac_start.out`, `linac_final.out`	`linac.out` files for standard and optimized runs.

This document was prepared in LaTeX on the `pc-lysenko.atdiv.lanl.gov` computer running Linux. The graphs were done with Gnuplot. The files associated with this document are in the `/home/wpl/projects/sns/DOC/matching` directory.

[3] It may be possible to reduce the slow variation also by varying not just the initial beam α and β values in the optimization but also some accelerator parameters, such as some of the quadrupole settings.

Files in /home/wpl/projects/sns/DOC/matching directory	
memo.tex	Source file for this memo.
t2memo.cls	T-2 memo class file (modified).
unmatchedfd.ps	Plot for standard-beam profiles in EPS format.
matchedfd.ps	Plot for optimized profiles in EPS format.
unmatchedfd.gp	Gnuplot commands file for generating unmatchedfd.ps.
matchedfd.gp	Gnuplot commands file for generating matchedfd.ps.
unmatchedfd.txt	Data for the unmatchedfd.ps plot; extracted from file sizestand.xls.
matchedfd.txt	Data for the matchedfd.ps plot; extracted from file sizeopt.xls.
sizestand.xls, sizeopt.xls	Excel spreadsheets containing data from beamsz_start and beamsz_final.

WPL:wpl

Distribution:
B. Blind, LANSCE-1, H808
T. Bhatia, LANSCE-1, H808
D. Bruhn, LANSCE-1, H808
R. Garnett, LANSCE-1, H808
D. Gilpatrick, LANSCE-1, H808
T. Hunter, LANSCE-1, H808
R. Jameson, LANSCE-1, H808
A. Jason, LANSCE-1, H808
J. Ledford, LANSCE-1, H808
G. Neuschaefer, LANSCE-1, H808
J. O'Hara, LANSCE-1, H808
H. Takeda, LANSCE-1, H808
N. Bultman, ESA-EA, P946
B. Bentley, ESA-DE, H821
M. Collier, ESA-DE, H821
Z. Chen, ESA-DE, H821
R. Gillis, ESA-DE, H821
T. Hargenrater, ESA-DE, H821
SNS Project Office, H824
LANSCE-1 File